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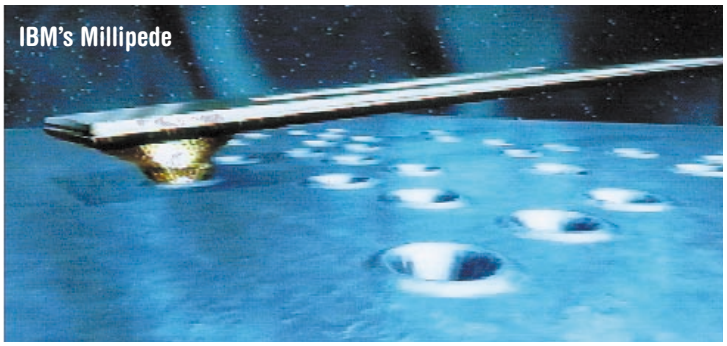
Inside IBM's Nanotech Lab

The news has not been good. **IBM's** [IBM] stock has been decimated in recent months and sits at a four year low. Sales in the last quarter are down nearly 12% from the prior year, reflecting continued weak industry demand. But despite the sluggish demand, the transition in management and the near-term uncertainty, IBM's future in nanotechnology burns bright. I recently took an insiders-only tour of IBM's top-secret Westchester County, New York facilities where I was treated to a preview of cutting edge nanotech developments set to revolutionize the storage and computing worlds.

IBM's T.J. Watson Research Center in Yorktown Heights is the center of the company's nanotech efforts. Facilities in Zurich and Palo Alto also do work in nano, but more than 50% of nanotech research occurs here.

Discoveries coming from Watson are hard to keep up with. Last year, IBM demonstrated one of the basic elements of a logic circuit using a carbon nanotube. This was quickly followed by the world's first array of carbon nanotube transistors, 500 times smaller than today's silicon version. They also created "constructive destruction" technology to separate


IBM's Millipede

metallic and semiconducting nanotubes—a big obstacle in the field today.

Its disk drive business has been continuously impacted here as well. IBM holds the record for taking a technology from concept to commercialization in the shortest time. In under 10 years, it took the GMR effect (Giant Mangetoresistive) to market with disk drives capable of storing 40 gigabits per square inch and allowing desktop computers to do complex video production. Today, we use this technology in PC hard drives. Next year, we'll see PC disk drives with 400% more capacity, offering 100 gibabits of storage. This technology is known within IBM as AFC (antiferromagnetically-coupled media) or, more affectionately, "pixie dust." It is essentially a three-atom thick layer placed between two magnetic layers.

The latest and greatest breakthrough is based on the thermo-mechanical movement of a parallel array of atomic force microscope (AFM) tips (a.k.a. "Millipede"), demonstrating a storage density of 1 trillion bits per square inch— 20 times that of today's best magnetic based storage.

Veeco Acquires FEI

On July 12, Veeco [VECO] announced a $989 million all stock acquisition of FEI [FEIC], its twelfth in 5 years. The new company, to be known as Veeco FEI Inc. [VECO], will be the third largest U.S. metrology company behind KLA-Tencor [KLAC] and Applied Materials [AMAT]. The move reflects the current down cycle in the semiconductor capital equipment industry, and I expect to see others like it in the next several months. Veeco stock hit a 52-week low on the news. Some may have viewed the 38% premium paid for FEI as too hefty, but I think this is a smart long-term move to capture market share and extend its reach in the growing nanotech market. In particular, FEI brings to the table a nanofabrication tool called the Small Stage Dual Beam and imaging tools like Scanning (and Transmission) Electron Microscopes. Veeco will likely create all-in-one research tools that will probably fetch double the price of Veeco's current $1 million offerings. The two firms share a lot of common clients including IBM, Seagate, and TDK, and FEI brings new customers like Intel, AMD and Samsung. Annual savings of $8-10 million are expected mostly from the combining sales staffs and from squeezing suppliers. Veeco CEO Ed Braun has shown proven skill at integration with previous acquisitions.

IBM's Nano-Research Strategy

When former Chairman and CEO T.J. Watson died in 1993, Lou Gerstner said, "Perhaps the most important legacy of his leadership can be summarized in just three words: IBM means service." The latest quarter has the service business comprising 44% of IBM's $18.5 billion top line. So it's no wonder that, despite inventing tools like the AFM, IBM is unlikely to sell them commercially.

Randy Isaac, IBM's vice president of science and technology, recently talked to me about IBM's strategy. "Our goal is technology leadership, and leadership means to get the rest of the industry to follow. If you're off doing your own thing and the industry doesn't follow—

INSIDE

you're not a leader, you're a loner. We look to enable an industry. For nanotech to be a vital industry force, there has to be an infrastructure of both analytical and production types of tools. We're highly motivated to ensure this happens. It is more cost-efficient than hiring instrument makers. IBM wants the world to have this capability and, as long as the industry is following, we're still ahead."

Tools are a critical part of IBM's strategy. Revenues may come from licensing these inventions, but, as Isaac says, the real long-term value is in getting the tools out on the market and creating a wide user base. IBM forces the electronics and data storage industries to adopt its tools as standards and follow the path it has carved out for them. IBM is also quietly developing competing approaches to replace the existing methods that players like **Intel** [INTC] and **AMD** [AMD] use to make chips and memory devices. One of those is an exciting aspect of nanotech called self-assembly.

Big Bets On Self-Assembly

IBM's self-assembly guru is Chuck Black. Expensive equipment blanketed his lab, but Chuck, who stands well over six feet, was nowhere to be found. Before I could ask where he was, a flash of a man came bursting through the door like Kramer from *Seinfeld*.

We huddled over an industry-standard 8" silicon wafer with circuits covering the surface. Some of the feature sizes of the transistors and interconnects on this wafer were as small as 200nm, already amazingly small. To go even smaller and still be economical, any nanotechnology approach must obey three rules. First, it has to be done with consistency. Second, it must be able to be done over relatively "large" areas (in this case 8"). Lastly, it needs to conform to the existing rules of microelectronics. It turns out that the best methodology at the nanoscale for this is self-assembly. This lets researchers do things they can't do with everyday tools.

He demystified self-assembly by placing a handful of marbles in a plastic petri dish. With a tiny push, they arranged themselves into a perfectly ordered pattern. In fact, most things will self-assemble if the objects involved are all the same size and some energy is added. Atoms self-assemble into perfect crystals all the time. So IBM has been trying to find molecules that will self-assemble to make nanoscale-patterned circuits tens of times smaller than what the machines that created that 8" wafer can do.

IBM settled on polymers, long chains of molecules connected together. These particular ones are called diblock copolymers, and scientists have known about them for 50 years. Their other properties, such as their ability to bind to other materials, have been used to prevent car dashboards from cracking after prolonged exposure to the sun. But nobody has ever used their self-assembling properties.

IBM started ordering them two years ago for a few hundred dollars per gram from Sunil Varshney, who runs a small operation in Canada called Polymer Source. The privately held company did sales of $2 million in 2001 on a host of related products. Vasrshney saw a huge increase in demand for the diblock copolymers from other companies across the country and in Europe and Japan as soon as IBM published a paper on its self-assembly work.

The work is cutting edge and IBM is very excited about it for future magnetic storage devices with greatly enhanced data density. IBM's strategy here is to introduce new nanotech discoveries step by step into the methods already used in its microelectronics division.

Logical Target: Intel

The next stop was to see the vice president of science and technology, Randy Isaac. In his large, windowless office, there was a foot high ingot of pure silicon sitting next to a small leafy plant on a conference table. Catching me studying this, Isaac reminded me that IBM hoped to pattern silicon into complex circuitry using a self-assembly process similar to that used by the plant for its growth and maintenance.

In the area of nanotech and logic, many are designing simple on-off logic switches and are assuming they can create memory devices. But Isaac says there are far fewer candidates for true logic functions. "One of the holy grails we're after is nanosystems that can handle logic. Carbon nanotubes are really the only example."

IBM is making a big push with carbon nanotubes. They can carry tremendous amounts of current without heating up or dissipating too much. IBM researchers say they are the ideal material for creating hybrid devices initially and then fully functional stand-alone devices. As detailed in an earlier *Forbes/Wolfe Nanotech Report* (see *Nanotubes: A Primer, May 2002*), IBM's broad coverage patent 1995 on nanotubes is key intellectual property in this arena. Since then, Richard Martel and Phaedon Avouris, among others, have been gaining a complete understanding of nanotubes and demonstrating breakthrough future devices.

Though not widely known, IBM researchers have recently discovered a very interesting and inexpensive way of fabricating high quality tubes. That's bad news for its current supplier: Nobel Laureate Rick Smalley's Carbon Nanotechnologies. It charges IBM $500 for a gram of the substance!

Finally, I met with Tom Theis, IBMs director of physical science. "Information is physical," he declares, reciting the mantra of the late IBM fellow, Rolf Landauer. "Manufacturing an object is patterning information into it." He's concluded that any new material takes 15 years to get into commercial use, like with copper and silicon germanium. "Nature doesn't give up her secrets easily; it takes time to get them out."

When asked about other startups doing molecular electronics, he offers the perspective of a market leader: "A lot of those companies don't understand they are in direct competition with IBM. $50 million of investment per year has been par for the course. They might find a niche, but the major players will win." According to Theis, the next year will determine the fate of IBM's Millipede data storage system. He says it won't cannibalize hard disk drives, but will instead go into the ever-growing number of consumer products. He also told me that the sensors arena is wide open. IBM may soon announce nanoscale work here with cheaply fabricated and very sensitive detection tools that could rapidly detect the presence of specific biological or chemical molecules. You can bet that if IBM doesn't think it can impact the top line, it will write a patent, publish a paper, get some publicity and license it.

Continuing a nine-year streak, IBM was awarded the most U.S. patents in 2001, with a record 3,411. Since 1989, at least 700 have been nanotech-related. Shrewd investors buy stock in a company to capture future growth prospects. The nanotechnology franchise IBM is building will spawn new technologies—from storage to semiconductors—and new companies. In terms of revenues or stock price, nanotech is not yet a big deal at IBM. One day it will be.

PHOTO COURTESY IBM

Nano in the News

New technique for fabricating microchips?

Princeton's Stephen Chou, founder of NanoOpto (*see Thinking Small, April 2002*), announced a significant new approach to make nanoscale features on silicon. LADI (laser assisted direct imprinting) uses a stamp and an excimer laser to make structures directly on silicon. LADI may be able to print faster and cheaper transistors than standard methods of photolithography.

Symyx Finds a Catalyst in Nanomaterials

Stop me if this sounds familiar: A tech company is born in Silicon Valley with backing from top venture firms NEA, Venrock and IVP. CSFB leads a November 1999 IPO and the stock rockets into the stratosphere. Amidst soaring revenue growth and management's assertion that it is "revolutionizing" its industry, it is valued in excess of 100 times sales and has a multi-billion dollar market cap. But, unlike most other high-tech high flyers, this company didn't buy growth through costly and dilutive acquisitions, nor did it lose customers during the economy's cliff dive.

Though Santa-Clara, California-based **Symyx Technologies** [SMMX]'s stock ($12) is way off from its $80 2000 high, it has set itself apart from other tech wrecks with its consistent growth and profitability. From 1998 to 2001, Symyx's revenue grew from $13.8 million to $60 million (a CAGR of 63%), achieved and sustained profitability and added to its stable of blue chip customers. Symyx now has 25 clients, including **Dow Chemical** [DOW], **ExxonMobil** [XOM], and **Merck** [MRK]. In part because of the tech sell-off, investors aren't focusing on Symyx these days. In fact, I think it is largely misunderstood by Wall Street.

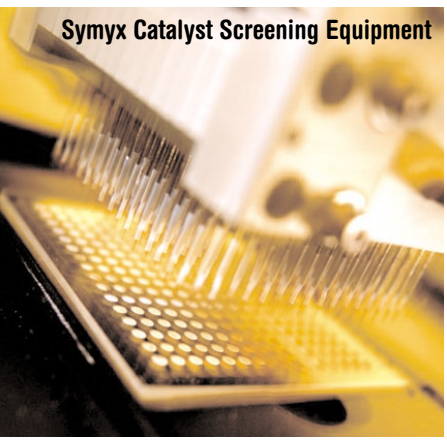
"I have no illusions that most investors even know who we are," says Symyx Chairman and CEO Steven Goldby.

Well, Symyx is the leader in high-throughput materials screening—another word for experimentation using a sophisticated large scale trial and error technique. It was founded by legendary scientist and entrepreneur Dr. Alejandro Zaffaroni, who also started Alza, Affymax and **Affymetrix** [AFFX]. Symyx employs high-speed large scale trial and error methods for materials science research in the same way Affymax and Affymetrix use them in pharmaceutical and genomic research.

"Historically, new materials were created by slow, tedious experiments, one at a time, producing very few solutions," says Goldby. "We've borrowed the philosophy from pharma companies so that our scientists can do hundreds if not thousands of experiments at once. Our methods of new materials discovery are faster, lower cost, and more efficient."

Symyx estimates the company's 150 scientists are able to conduct research 100 times faster than the internal efforts of companies like **BASF** [BF], reducing costs in the process by up to 99%. Symyx has created an intellectual property fortress with over 60 issued U.S. and European patents and over 360 patents pending covering Symyx's methodology, instrumentation and materials discoveries.

"People have forgotten that materials can create huge opportunities," says Goldby. "**DuPont's** [DD] Nylon created $15 billion in profits. UOP's Platforming Catalyst for high-octane gasoline saved 70 billion gallons of gas. If you look at when there was a lot of innovation in materials, there was huge growth. But traditional research methods have played themselves out."



Symyx Catalyst Screening Equipment

Goldby estimates that 20% of the Symyx's research is done at the nanoscale in its search for new heterogeneous catalysts, a $9.7 billion market. A catalyst is an agent that accelerates a chemical reaction but is itself unchanged in the process. They are solid materials with the capability of adsorbing molecules of gases or liquids onto their surfaces to enable chemical reactions to proceed more rapidly or at a lower temperature. Catalysts are used in the chemical processes necessary to make things like pharmaceuticals, plastics and fuel cells.

Symyx has struck deals with ExxonMobil and **Celanese** [CZ] to develop new catalysts to lower the manufacturing cost of commodity chemicals. Symyx also recently extended a 3-year collaboration with Dow (14% of 2001 revenues) to create new catalysts for pharmaceutical intermediaries and the manufacture of polyolefins (a family of polymers including polypropylene and polyethylene). Polyolefins comprise close to 25% of Dow's $27 billion in annual revenues and are used to make products ranging from milk jugs to lawn furniture to water bottles. The collaborations are scheduled for commercialization between 2003-2005.

"When we initially looked at high-throughput screening to speed up catalyst discovery, we had to decide whether to build or buy," according to Dow's Kurt Swogger. "We made the decision in a hurry: We bought."

Before developing a new catalyst, Symyx screens how well a material performs a specific chemical reaction. Examples of catalytic materials include metals like platinum and palladium, metal oxides, and crystalline materials like zeolites. Targeted materials are rapidly screened in parallel for desired properties at the nanometer size scale, including chemical, thermal, optical, electronic or mechanical attributes, to produce as few byproducts as possible. Nanotech can improve catalysts in two ways: nanocrystalline materials boast a high surface-to-volume ratio, increasing the efficiency of surface catalysis; the ability to process nanoporous (pores less than 100nm in size) materials with greater control opens up opportunities for advancing catalysis and separation technologies.

The Netherlands' Avantium and Germany-based HTE are Symyx's biggest competitors in this area. Avantium poses a significant threat to Symyx in the life sciences arena. A spinout of Shell Chemical, privately held Avantium counts **Pfizer** [PFE] and **GlaxoSmithkline** [GSK] among its shareholders. The company has raised 55 million Euros in total capital, including its most recent 31 million Euro round in February.

Avantium CEO Ian Maxwell says that while the materials industry will continue to demand innovative new catalysts, introducing catalysis to the relatively virgin pharmaceutical industry offers a greater opportunity. He estimates 10% of pharma companies use catalysts in the manufacturing process compared to nearly 100% of materials companies. HTE differs from Symyx because its high-throughput experimentation is specifically focused on the catalysis market. The closely held company makes money through contract research, tool sales and also retains incentive-based revenues streams on discovered materials. HTE counts **BASF** [BF] and **ChevronTexaco** [CVX] as collaboration partners.

If competitive threats by Avantium or internal efforts of large corporations have worried Symyx, it has certainly not been visible in the company's performance. In the most recent March quarter, revenues grew by 4% from the previous year to $14.5 million. Product and license revenue jumped 39% to $5.8 million. UBS Warburg estimates SMMX will earn $0.25 per share on $81 million in revenues in 2002 and has modeled a 2003 EPS of $0.42 per share on $103 million in revenues. It has a strong balance sheet with $116.4 million in cash and no long-term debt.

Symyx has a 3-pronged business model. Its main revenue generator is industry collaborations: partners like Dow fund R&D programs in exchange for exclusive rights to commercialize any materials discovered.

Symyx has a pipeline of 12 product development candidates, many of

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Nanofiltered Water

The Petroleum of the 21st Century

Water will be the oil of the 21st century. Don't believe me? Look at the recent move of oil tycoon T. Boone Pickens to privatize groundwater sales in Texas. Then consider the following: 20% of the world's fresh water supply is in Canada and 60% of the world's desalination plants are in the Middle East. And after two India-Pakistan wars since the 1960 Indus Water Treaty, in which India agreed not to cut off Pakistan's water supply, the idea is being seriously discussed. Already, the World Bank estimates some 1 billion people in over 29 countries have poor access to clean drinking water and 3 billion lack sanitary sewage facilities.

In some locations this is so bad that, according to John Doerr, venture capitalist at Kleiner Perkins Caufield Byers, "Sixty-five thousand people will die today, and principally they'll die of dysentery because their drinking water was polluted by human waste. That's the single largest cause of death on the planet."

Fortunately, most of the problems with water here in the United States are mitigated by our proximity to lakes, rivers, and freshwater sources in Canada. We're not immune to water crises however. The National Safety Council estimates that in a few years, more than a billion pounds of lead, two million pounds of cadmium, and 400,000 pounds of mercury from discarded personal computers will exist in U.S. landfills, possibly seeping into groundwater. When you add to that recent droughts and fears of chemical and biological attacks on our drinking water systems, the U.S. is clearly in need of better filtration technology.

Filtration Going Nano

Drinking water filtration technology in the United States had largely been the same for the past 200 years, using beds of sand or charcoal to filter contaminants. One event in 1993, however, changed all of this. Thousands of residents of Milwaukee, Wisconsin got sick off a microorganism in the drinking water and hundreds died. This caused a major shift in the water industry's focus on purity, opening the door to a now widely-used filtration technology: membranes. Membranes, porous polymer or acetate films that absorb inorganic (heavy metals like mercury) and organic (viruses) contaminants, have become norm over the past few years. And due to recent Environmental Protection Agency (EPA) requirements meant to lower the amount of arsenic in drinking water to 10 parts per billion by 2006, water companies are turning to nanotechnology to help them achieve this.

"It's estimated that these changes will cost $1.5 billion annually," says Peter Erikkson, Senior Engineer at Minnetonka, Minnesota-based **Osmonics** [OSM], one of the world's leading water purification and filtration companies. Because of the EPA's ruling, water filtration and purification is all of a sudden a hot sector: Shares of Osmonics are up 30% since February.

Challenges and Opportunities for Nanofiltration

The four main filtration methods available to municipalities are microfiltration, ultrafiltration, nanofiltration, and reverse osmosis (commonly used in desalination). The degree of purification required determines what level of filtration is appropriate. The important difference between these methods is membrane pore size. Microfiltration, often the first line of defense, is used on the largest particles in water, siphoning off dirt and other micron-sized contaminants.

Nanofiltration, however, offers several advantages. Nanofiltration pore sizes are 1–2nm, offering the critical advantage of being able to absorb molecular organic substances like pathogens. Another nano-enabled technology used nanosized molecules called ligands. Ligands can bind to harmful metals like lead, chromium, and mercury and makes it easy to remove these substances from water.

Mark Wiesner, Director of Environmental & Energy Systems Institute at Rice University agrees that nanotechnology is driving progress. "Nanotech will reduce one of the largest problems in the water filtration membrane business: fouling (clogging) because it lets you dramatically smooth out the surface of the membrane. Nanotech also allows us to selectively filter out harmful materials." Wiesner estimates the market for cleanup, protection, filtration of water is $123 billion.

So as an investor, how do you profit from the use of nanotechnology in the water market? One way might be to follow the basket of stocks traded in the recently U.S.-launched **Pictet Global Water Fund** [PGWRX]. Fund co-manager Philip Rohrer sees the following scenario playing out: "I see infrastructure renewal as the big opportunity. A lot of the infrastructure in the United States dates back to World War II and has largely been ignored. Equipment manufacturers who are improving water treatment plants and pipelines stand to benefit." **Insituform** [INSUA] is one example Rohrer mentioned. Insituform specializes in trenchless repair of city pipe systems, which reduces the need for expensive construction sites which disrupt traffic. The stock currently trades around $17.

On the private side, Bill Reilly, former director of the EPA, now runs Aqua International Partners, a $232 million private fund that backs companies in the water sector. And the tie to nanotech? He's also on the board of directors for nanomaterials leader **DuPont** [DD] which, along with Nitto Denko subsidiary Hydraunatics, controls the majority of the reverse osmosis membrane business. Reverse osmosis is even more precise than nanofiltration; it uses a membrane to apply pressure to literally push the salt out of seawater. There is a need for nanotech-engineered membranes in order to reduce the cost of this process in order to make it more commercially viable.

Where Do We Go From Here?

As the demand for water continues to increase twice as fast as the world's population, I predict two things: recent EPA changes in the levels of acceptable arsenic and disinfection of cryptosporidium in our drinking water will increase sales of membrane and ultra-violet (UV) disinfection technologies. Companies like Osmonics and **Calgon Carbon** [CCC], a leader in water disinfection, will benefit.

And worldwide, with 97% of the Earth's water oceanwater, energy efficient desalination is the holy grail of the water industry. Nanoscale enhancements to membrane technology will drive costs of membranes to levels where widescale desalination becomes economically affordable. Don't be surprised to see **Symyx** [SMMX], one of my Nanosphere companies and a top player in the specialty chemicals discovery arena, announcing some partnerships with major water membrane companies.

Nano in the News

DuPont acquires NanoSource

After only three years in business, Oklahoma City, Oklahoma-based nanomaterials company NanoSource has been acquired by DuPont [DD]. NanoSource produces a variety of nanomaterials, including Titanium Dioxide nanoparticles, commonly used in suscreens to block harmful UV light. Terms of the deal were not disclosed.

Thinking Small: Mike Roco

Mihail "Mike" C. Roco is the leading federal expert on nanotechnology. Mike chairs the National Science and Technology Council's subcommittee on Nanoscale Science, Engineering and Technology (NSET), and serves as Senior Advisor for Nanotechnology at the National Science Foundation. He was instrumental in the launch of the National Nanotechnology Initiative (NNI) in January 2001 with $422 million allotted from President Clinton's FY 2001 budget. Sixteen federal agencies now compete for nanotechnology research funding from the NNI. Under Dr. Roco's guidance, federal expenditure in nanotechnology research has grown from $116 million in 1997 to $710 million in 2003.

His passport is well worn and his thick accent exudes worldliness. Roco has been a professor at Caltech, Johns Hopkins, Tohoku University in Japan, Delft University in the Netherlands and is a member of the Swiss Academy of Engineering Sciences. He has been author on over 250 publications and has patents for 13 inventions. His vision for the U.S. National Nanotechnology Initiative has been copied by nearly 30 countries and has created a competitive international race to claim worldwide leadership in nanotechnology.

What are your top 3 goals as chair of the NNI?

Firstly, my main role is to maintain a consistent vision and keep new ideas continuously coming to bring the benefits of nanotech sooner. And to not ever be satisfied with the level of development.

Secondly, it's crucial to maintain strong interaction between the members of the NNI and to expand the membership further. The FDA recently joined as the 16th member. We meet each month and generate new ideas for new programs or even international activities.

Thirdly, we must address societal implications, including maintaining U.S. competitiveness. It's important to keep all the breakthroughs in perspective: nanotech is a big part of an economic and social loop. Part of the strategy is to have an open interaction with the public and to keep in mind the main purpose is to serve society as a whole while ensuring the U.S. has a competitive lead.

This is the first time since WWII that the U.S. has not definitively led in a technology field and the worldwide funding race has begun. What would you attribute this to and what does it mean?

First of all, in nanoscience, the U.S. still has a lead position. It is a weak lead. But if you look at the outcomes and not just funding, a larger proportion of nanotech discoveries are coming from the U.S. That said, centers of excellence are distributed more and more around the world and other countries are following the model of the NNI. And they're doing it over a very short time scale. There are more than 30 countries that are using the basic concepts of NNI. But we don't have reciprocity. We provide lots of info to other countries, but don't get so much back. It's important to get more formal agreements to get a balanced exchange of information.

What trends do you see in nanotech funding levels?

The U.S. in the last 2 years has increased spending on nanotech, but it's smaller than the average increase worldwide. In 2002, the U.S. increased spending 43%, but the rest of the world increased over 80%. In 2003, we have a request for a 17% increase, while Japan is planning a 68% increase and Europe is increasing their long-term plans by a factor 3.

Also, the U.S. contribution from the government has decreased from 33% of the total amount spent worldwide in 2000 to 28% this year and will likely decrease further next year. That said, one of the good signs is that over the last year, states and private foundations have also begun funding nanotech to the level of 50% of what the NNI provides and industry has contributed about the same total amount as the government in nanoscience and engineering. The weakness in the longer term is lack of sufficient qualified people: the training has to start even before high school.

How many people will be needed to meet the NSF's prediction that nanotech will be a $1 trillion global industry by 2010-2015?

Two million. This number came from considering that each nanotech worker will have $500,000 per year in output product and thus $1 trillion product in 2010-2015.

The U.S. alone will need 800,000 workers trained in some area of nanotech, which would be 40% of the total. If you consider the distribution of tools like SPMs (Scanning Probe Microscopes), about 40% are sold and used in the U.S. So the numbers correlate. Even if we spent 30%, I think because of the better infrastructure, we are more efficient from the point of view of number of people involved and the number of breakthroughs for the same amount of money.

In the U.S., if you consider we have 200 universities and each one has on average about 100 nano-qualified students and professors and industry has the same number, we have about 40,000 that are currently able to work in some aspect of nanoscale. But there is still a gap.

The NSF is funding the education and training of about 6,000 students and teachers in nanotech. Next week there will be an announcement for a new nanotech undergraduate education and we're also working to develop programs for K-12 education to change the way science is done. We plan in 5 years to give 50% of undergrad and grad students access to nanotech courses and labs. Not that they will all take it, but they will have access if they choose to do it.

Why should the public care about nanotech?

Three simple reasons: Economy, defense and healthcare. I think the quality of living and salaries will be heavily affected in the next 5-10 years. And, with a growing and aging population, more people will be demanding a higher quality of healthcare specific to each individual.

What about investors?

In terms of companies in advanced materials or pharmaceuticals or advanced electronics, if they don't enter nanotechnology now, in another 5-10 years, they won't be able to compete. It will be a condition to remain competitive. In several years, you will go to the pharmacy and take a drug according to your DNA and if a drug company can't do this, they'll be out of business. Changes are coming and companies need to have the foresight.

Nano in the News

Nanoparticles cut tumors' supply lines

In what's being called a "landmark in angiogenesis research," researcher David Cheresh of Scripps Research Institute in La Jolla, California packed a tiny particle with a gene that forces blood vessel cells to self-destruct, then precisely delivered the particle to blood vessels feeding tumors in mice. A single treatment erased large tumors in mice in about 6 days. More animal tests are needed before attempting this treatment in humans.

Companies to Watch

BioForce Nanosciences

(private)

www.bioforcenano.com **515-296-6550**

Ames, Iowa

Chief Executive: Gary Alianell

What it does: Develops nanoarrays to run protein interaction analysis.

Since the completion of the Human Genome Project, the biotech industry has embraced the field of proteomics. Proteomics is based on a concerted effort to map and better understand the interaction of human proteins. Because proteins control all cellular processes by translating genomic sequences into functions, understanding protein interactions is critical to identifying diseases and discovering new drugs and new therapies. Companies like **Agilent** [A], **PerkinElmer** [PKI], and **Ciphergen Biosystems** [CIPH] produce devices called microarrays to analyze the interaction between proteins. But currently available microarray technology suffers because of the large sample sizes required to conduct tests. This is a major problem because individual proteins cannot be easily increased in quantity and obtaining these larger samples can dramatically increase research costs.

BioForce Nanosciences solves this problem with its NanoPro technology platform. NanoPro utilizes "NanoArrays," which can measure interactions between individual molecules down to a resolution of 1 nm. The NanoArrays use roughly 1/10,000th of the surface area of a conventional microarray, thereby reducing the requirement for sample material by 1000 times.

"The time it takes to run an array shrinks with NanoPro," says CEO Gary Alianell. "Drug discovery people have thousands of variations of compounds they want to test before it is worth looking at a second time. We allow them to pass over an array of 10,000 samples to find the 10 that work."

Another advantage of BioForce's NanoArrays is that they can be used "in solution" (a patient's blood for instance). Microarrays must be removed from solution and rinsed before they are scanned to obtain results. This takes time and the rinsing can also lead to the degradation of the array and damage to the sample. The NanoPro systems can read the NanoArrays while they are still immersed in solution.

Founded in 1994 by Iowa State University professor Dr. Eric Henderson, BioForce is guided by a team of experienced hands. Seasoned biomedical executive Alianell joined the company in April. He was previously the COO for drug discovery company EraGen Biosciences. Henderson, who is Chairman and Chief Scientific Officer, pioneered the development of many Atomic Force Microscope biological applications while at ISU.

BioForce anticipates revenues of $1.5 million in 2002, driven by grants, technology licensing, and AFM accessory sales, but expects sales to surge to $10 million in 2003 when the NanoPro system hits the market in Q2. The protein array market is expected to reach $490 million by 2006.

Alianell said the company is closing a $3 million Series A institutional round, led by Société Générale, within the next few weeks. BioForce has already generated $3.8 million from government grants since inception. In June, BioForce was awarded a $250,000 government grant to develop a NanoArray that can rapidly detect biological warfare agents and pathogens like anthrax and smallpox. BioForce also announced a research collaboration with the National Cancer Institute and the FDA in May to use NanoArray technology for the screening of Ovarian Cancer.

Rolltronics

(private)

www.rolltronics.com **650-566-8471**

Menlo Park, California

Chief Executive: Michael Sauvante

What it does: Developing a manufacturing process to print electronic circuits and devices.

Today's electronic components today are designed individually and made in a batch process. But now comes Menlo Park, California-based Rolltronics, which wants to print circuits like newspapers. Rolltronics calls it roll-to-roll or "web" processing and it says it will make electronic devices with features that are thinner, lighter, more flexible, more durable, more affordable, and quicker to market than conventional methods.

The process starts with large rolls of flexible plastic that are 1 meter wide and can be as long as 10 kilometers. The sheets of plastic then feed through an series of rollers where silicon is first deposited on the surface, then patterned and finally packaged to yield finished components. The company is also exploiting nanoscale organic molecules called porphyrins that can self-assemble on the surface of the sheets.

Rolltronics' CTO Dr. Jim Sheats and CEO Michael Sauvante met while working at HP Labs back in 1998. Sheats joined Rolltronics full time in March after nearly 20 years at HP. He says the germ of the idea came while they were there, but when he tried to interest management in the concept, it didn't "pass the strategic cut."

Over $15 million of R&D and 12 man-years of research have gone into creating the patent portfolio, licensed from Lawrence Livermore National Laboratory and Dr. Allen Bard's nanotech work at the Univeristy of Texas-Austin. Now, the company is actively raising a $3-5 million venture round to attack the $60 billion memory market. Prototype development over the next 9-12 months will yield a 650MB memory device called NanoMem. Retail prices would be about 1/3 or 1/5 of corresponding flash RAM units. It would be available commercially within 18 months.

But is three times cheaper enough to gain industry support? According to industry insiders I've spoken to, a new memory device today would have to be 1/10 of the cost to really capture attention and interest from big electronics players like Sony and Sharp. But Sheats maintains, "Not only will it be cheaper, but it's demonstrated better longevity. Flash lasts for maybe 100,000 read-write cycles. We've shown over billion."

The second NanoMem product is the 64GB PC memory card slated for 2005, which will offer a 100-fold increase in data storage capacity over existing flash memory products. This is enough capacity to store 10,000 books, 40 hours of CDs, 10,000 photos and 10 full-length DVD movies. A disk-drive sized device connected via USB cable would have the potential to hold 100-times that, or 5 terabytes.

The playing field is getting crowded, though. A host of start-ups and major companies, including **3M** [MMM], **Lucent's** [LU] Bell Labs, and **IBM** [IBM] are exploring both the nanoscale molecular memory field and the R2R field. But they are optimistically seen by Rolltronics as future customers and partners rather than competitors.

"Our preferred business model is to work with the manufacturer of the final product to actually do the production," says CTO Sheats. "They'll have the market presence, the brand recognition, the good understanding of handling high volumes." However, I expect to see a licensing strategy followed by an early strategic acquisition by a leading memory player.

Follow the Money

A monthly look at who in nanospace is getting funding and who's giving it.

Venture Investment

Reactive Nanotechnologies

www.reactivenanotech.com

Location: Baltimore, Maryland

Lead Scientist/CEO: Omar Knio/Timothy Wiels

Funding Announced: 6/26/02

Investors: Toucan Capital Corp.

Funding Amount: $2 million (Series A)

Notes: Have 3 existing patents and 4 patent applications for improving the way electronic component manufacturers join parts together. Its "nano-furnace" technology is based on the chemical reaction of thin foils that contain hundreds of nanoscale layers. The use of reactive foils as a heat source eliminates the need for other less accurate and more damaging methods such as torches, furnaces, lasers, and other soldering processes.

Outlook: Founders are world-class researchers from Johns Hopkins, Lawrence Livermore National Labs, and MIT with over 20 years experience in reactive joining technologies. However, with semiconductor sales down over 40% from their 2000 peak and the future uncertain, Reactive faces a less than ideal market for its new technology. With its main markets being semiconductor heat sinks and hermetic sealing for microelectronic devices, Reactive is walking into a firestorm of cap expenditure challenges: Watch to see if they remain an IP holding company or actually try to build a capital intensive fabrication plant.

Optiva

www.optivainc.com

Location: San Francisco, California

Lead Scientist/CEO: Pavel Lazarev/Robert Duboc

Funding Announced: 6/19/02

Investors: AAFA Holdings, Altotech Ventures, ESN Group, **Harris & Harris Group** [TINY], NextGen Partners and Noval S.A.

Funding Amount: $9 million (part of ongoing $15-20 million Series C round)

Notes: Optiva's technology can create 30% thinner—60 microns thicks — and less complex liquid crystal displays than are currently available today. The technology creates a thin crystal film polarizer (which controls light intensity) with a submicron profile that can be printed directly onto glass or plastic. The company claims that its LCD's are more durable and have brighter colors than current displays. Will put the funding towards applications for its new class of optical films for the flat-panel display industry.

Outlook: A manufacturing agreement with Sony Magnetic Products of America provides them with scaleable production capacity, but Optiva faces competition from other types of nanomaterials, like the carbon nanotubes that flat panel display market leaders Samsung and NEC are embracing and plasma display technology. Faces further pressure from growing support of OLEDs (organic light emitting diodes) as a replacement for LCDs. The OLED market is expected to grow tenfold to $2.7 billion by 2005.

Nanolayers

www.nanolayers.com

Location: Jersusalem, Israel

Lead Scientist/CEO: Shlomo Yitzchaik (Hebrew University of Jerusalem)

Funding Announced: 6/5/02

Investors: Millennium Materials Technologies Fund, Summit Financial Investments

Funding Amount: $300,000 (seed)

Notes: Developing a way to grow single- and multiple-molecule layers based on molecular layer epitaxy, a method for producing thin films for use in the flat panel display or semiconductor industry. Nanolayers claims it can bring contemporary microelectronic production methods down to the nanoscale/molecular level. Potential applications include OLEDs, organic-field-effect transistors and biosensors.

Outlook: Difficult to say. The company is at a very early stage and it is unclear as to what its end applications and markets will be. Israeli investors Millenium may have hedged any concerns over materials businesses traditionally not being good venture investments by investing in 8 other material businesses over the past few years, all of which could be roll-up opportunities for one of the major specialty chemical incumbents like **BASF** [BF].

State And Government Funding

Nevada State University System

Funding: National Science Foundation

Funding Announced: 6/22/02

Funding Amount: $9 million

Notes: A three-year grant, to be bolstered by $4.5 million from the state and university system, will be distributed to the University of Nevada-Las Vegas, the University of Nevada-Reno, the Desert Research Institute and the Community College of Southern Nevada. The funding will go toward developing atomic and molecular scale designs of new materials and devices and advanced computing and biomimicry research. Biomimicry is a new science that tries to apply designs and processes found in nature to technology applications.

Brookhaven National Laboratory

Funding: Department of Energy

Funding Announced: 6/14/02

Funding Amount: $85 million

Notes: Secretary of Energy Spencer Abraham announced that department plans for a nanoscale research center at its Brookhaven National Laboratory on Long Island will move ahead, pending final Congressional approval. The Brookhaven Nanocenter will focus on six areas: examining changes in the electronic response of metal oxides with nanoscale dimensions for improved materials discovery; magnetic interactions in nanomaterials; nanocatalyst formation; molecular wires; self-assembly of thin organic films; and applications such as building nanoscale electronic devices, ultrathin-film optical devices and advanced fuel cell catalysts.

The Nanosphere

Company [symbol]	Technology	Coverage Initiated	Current Price	52 Week Range	Market Cap ($mil)
Intellectual Property Incumbents *Leading researchers in nanotech, with big potential for spin-offs and revolutionary breakthroughs.*					
IBM [IBM]	Nanoscale storage and nanotube transistors	3/02	$69.21	$66.10–$126.39	$118,480.00
Hewlett-Packard [HPQ]	Molecular transistors and switches	3/02	15.27	12.50–28.10	46,814.00
Instrumentation *Tools that allow researchers to view and manipulate nanoscale matter.*					
Veeco [VECO]	Atomic Force Microscopes	3/02	18.05	18.05–41.70	524.20
Materials *Companies producing nanoscale materials with novel properties that have applications across a wide range of industries.*					
Symyx [SMMX]	Novel materials discovery	3/02	11.92	11.66–27.20	366.98
Modeling *Companies developing software to visualize, model and simulate matter and activity at the nanoscale.*					
Accelrys/Pharmacopeia [PCOP]	Molecular rendering and analysis software	3/02	7.66	7.48–19.32	178.87
Platform Technologies *Companies that have corralled key intellectual property that will be the foundation of future developments.*					
Nanosys [private]	Nanowires and nanostructure-enabled devices	3/02	n/a	n/a	n/a
Investment Firms *Companies that are investing in promising early-stage nanotechnology startups.*					
Harris & Harris Group [TINY]	Non-volatile RAM, drug delivery, nano-optics	5/02	2.34	1.55–5.550	20.74

Company Updates:

IBM: IBM's stock fell to levels last seen in 1998 amidst cuts in revenue and reduced earnings estimates from Morgan Stanley, Lehman Brothers and Goldman Sachs. The Wall Street heavyweights cited a slowdown in tech spending and the sale of its hard disk drive business as rationale for lowering numbers. Despite trimming her financial forecasts, Goldman analyst Laura Conigliaro called IBM "a market-share gainer rather than loser."

HPQ: HP stock has dropped to its lowest levels since 1996. Nanoscale R&D may serve as a focal point for the company's long-term strategy, but HPQ's near-term attention is fixed on cutting costs. It hopes to achieve cost savings of $3 billion as it starts laying off thousands of its 150,000 employees.

VECO: The merger announcement with FEI (*see p.1*) raises research market efforts, as a portion of total sales, from 33% for all of 2001, to 41% in the first quarter of 2002. Though nanotech is an integral part of Veeco's business, it is classified as a semiconductor capital equipment company. Veeco's late-July earnings call will provide a pulse on the chip capital equipment business. Many believe the rate of recovery for the chip equipment business is slowing rather than accelerating. The June quarter is typically the weakest for chip vendors and these trying conditions may stall new order activity for equipment companies like Veeco.

SMMX: Symyx avoided the stock market's barrage by hunkering down to focus on business and uttering nary a word. Despite this absence of news flow, Symyx remained virtually unmoved. With 12 product development candidates and 7 new materials on the verge of becoming candidates, patient Symyx investors should be rewarded with a host of positive catalysts in the upcoming months.

PCOP: Shares of Accelrys' parent continue to float aimlessly in the high single digits. The company is using its dominant position in materials modeling and simulation to attack the life sciences market. Accelrys introduced the first suite of Windows-based bioinformatics applications for its Discovery Studio platform. It is designed to reduce the time and cost for the discovery and development of new drugs and therapies.

TINY: Harris & Harris stock traded sharply lower as investors priced in the removal of the Rights Offering premium. To raise additional capital from current investors, TINY gave shareholders of record on June 28 the right to purchase one additional share at $2.25 for each three shares they own. The stock officially began trading ex-Rights Offering on July 1. Expect more near-term uncertainty until the Offering expires on July 26.

*Stock prices as of July 12, 2002

which could be commercialized within two to three years of discovery, and 7 new materials on the verge of being candidates. One example is an X-ray phosphor for digital radiography licensed to Agfa. Symyx also discovered new polymers to increase the speed of DNA sequencing, signing **Applied Biosystems** [ABI] to a late-stage licensing agreement for the material.

The second prong of the business model is the royalty stream from licensing arrangements. Partners pay for Symyx to discover and optimize materials, processes or formulations and Symyx gets a percentage of the upside of successful new materials discovery commercialization. Symyx will take 1%-3% of a material's sales in a commodity chemical project. If the discovery comes from an internally funded project or is a remarkable breakthrough, Symyx can command up to 20% of sales.

Finally, the company sells and licenses selected instrumentation, software and intellectual property. Symyx sells its discovery tools to ExxonMobil to help the company develop catalysts for polyolefins. ExxonMobil says it uses catalysts with shape-selective, nanoscopic channels to get 50% more gasoline from a barrel of oil and double its production capacity for polymers.

Goldby sees licensing deals from the research collaborations business as the most significant long-term opportunity, but the tools business to pharma and chemical companies as serving as a huge cash driver for Symyx in the next several years. ¤

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